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Production Characteristics of All-male and Mixed-sex Giant River Prawns, *Macrobrachium rosenbergii*, Grown in Earthen Ponds in Kentucky and Mississippi USA

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Abstract

Production and population characteristics of monosex male (all-male) giant river prawns, *Macrobrachium rosenbergii*, were compared with a normal (mixed-sex) population in separate studies in Mississippi and Kentucky (USA) under low and high density stocking conditions, respectively. In Study 1 (Mississippi), juvenile prawns were stocked into eight 0.05–0.06 ha ponds at 24,700/ha. The mean stocking weight of all-male was 0.34 g and mixed-sex was 0.39 g. Prawns were fed 23% crude protein "range cubes" and harvested after 120 d for the all-male prawns and 112 d for mixed-sex prawns. In Study 2 (Kentucky), juvenile prawns from each group were stocked into six 0.04 ha ponds at 60,000 juveniles per hectare. The mean stocking weight for all-male was 0.38 g and for mixed-sex juveniles was 0.34 g. Prawns were fed a commercial sinking pellet (33% protein) once daily at a standardized rate and harvested after 105 d. In both locations survival of mixed-sex prawns and all-male prawns was not significantly different and the final average weight of all-male prawns was significantly greater than the average weight of mixed-sex prawns. For the study in Kentucky, total production was not significantly different between treatments, whereas in Mississippi total production in the all-male ponds was significantly higher than in the mixed-sex ponds. For both studies, the production size index of all-male prawns was significantly greater than that of mixed-sex prawns. In terms of population structure, in all-male ponds there was a significant increase in orange claw (OC) males compared with the mixed-sex ponds both as a percent of sex and a percent of total population. The increase in OC numbers in all-male populations may be due to a lack of females to stimulate the transition of males to the final, sexually mature, blue claw stage. As target weights increase from 20, 30, and 40 g, the all-male populations were increasingly superior in terms of production (kg/ha) of those target sizes. The economic benefit of all-male over mixed-sex populations will be principally based on an examination of tradeoffs that primarily consider the cost difference of juveniles relative to the price differences for different final harvest weights.

In temperate climates, production of the giant river prawn, *Macrobrachium rosenbergii*, is temperature limited to a single seasonal crop with approximately a 100–180 d growing season (Tidwell and D'Abramo 2010). Under the constraints of temperate zone culture, pond

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production rates must be maximized to achieve commercial viability. Many technologies have been evaluated to increase per unit production (kg/ha) of prawns including addition of artificial substrate in ponds (Tidwell et al. 2000), stocking larger juveniles (Eble et al. 1977; D'Abramo et al. 1989), increasing stocking densities (D'Abramo et al. 1989), size-grading animals prior to stocking (Daniels et al. 1995), and selective harvest of large animals periodically throughout the growing season (D'Abramo et al. 1995). Despite these efforts, expected mean yields of prawns under practical temperate zone conditions (1120 kg/ha; D'Abramo et al. 1995) remains far below the yields of other commercially grown species such as white shrimp, *Litopenaeus vannamei* (6500 kg/ha; Sookying and Davis 2011), and channel catfish, *Ictalurus punctatus*, or the blue/channel hybrid, *I. punctatus* × *Ictalurus furcatus* (5050 kg/ha; USDA 2010).

Monosex culture is widely utilized in some terrestrial livestock and fish culture industries. In giant river prawn production, monosex culture may reduce the problem of dramatic sexual dimorphic size difference between some male and female morphotypes, with most male morphotypes being larger. Also, monosex aquaculture populations are nonbreeding, so more of their energy is invested into somatic growth rather than reproductive expenditures, such as egg formation and mating behaviors (Malecha et al. 2010).

Early investigations of all-male prawn culture involved manually sexing juveniles in small cage experiments. Sagi et al. (1986) reported that in a 150 d study an all-male population yielded 473 g/m^2, mixed-sex yielded 260 g/m^2 and all-female yielded 248 g/m^2. Later Cohen et al. (1988) evaluated monosex prawns in more intensive production conditions in earthen ponds. Total yield of all-male was 2200 kg/ha compared with 2041 kg/ha for mixed-sex and 1640 kg/ha for all-female with average weights of 37, 30, and 24 g, respectively.

These studies involved manually separating juveniles by sex prior to stocking. This practice is currently utilized in India where all-male production is considered more profitable, despite higher costs for all-male juveniles. Nair et al. (2006) reported all-male monosex culture to be 63 and 60% more profitable than mixed-sex and all-female production, respectively. However, in countries with higher labor costs, manual sexing is not economically justified (Hulata et al. 1988; Sagi and Aflalo 2005).

A number of methods have been evaluated for producing monosex prawn populations including: manual sexing (Nair et al. 2006), use of male hormones to produce predominately male populations (Baghel et al. 2004), and hormone inhibitors such as dopamine (Ohs et al. 2006) to produce predominately female populations. Another method (used here) requires the removal of the androgenic gland early in the development of sexually immature males, causing them to revert to reproductively competent neofemales which are homogametic (zz) (Malecha et al. 2010) and capable of producing all-male progeny (Sagi and Cohen 1990). Recently, a gene silencing method that produces large numbers of all-male juveniles without surgery, chemicals, hormones, or genetic modification has been developed (Ventura et al. 2012). With the development of these effective and labor efficient processes, monosex culture of prawns may now be a practical management tool in commercial prawn production. The objective of this study was to evaluate the production characteristics of all-male prawns when used in semi-intensive pond production during the relatively short grow-out period in temperate regions.

Materials and Methods

Two independent experiments were conducted in Kentucky and Mississippi. For comparative purposes, stocking density in Kentucky was much higher than that of Mississippi, that is, comparing low input versus high input semi-intensive management practices as described by Tidwell and D'Abramo (2010).

Study 1 – Mississippi (Low Input/Low Density)

Eight earthen ponds (0.05–0.06 ha) located at the South Farm Aquaculture Unit of Mississippi State University were supplied with vertically orientated substrate (orange plastic fencing) at a rate of 25% of the bottom surface area (calculation based on the surface of a single side, mesh included, length × height). Ponds were filled with well water approximately 1 mo prior to the stocking of juvenile prawns. Pre-stocking management practices followed and included an initial application of an organic fertilizer (cottonseed meal) at a rate of 224 kg/ha and an inorganic fertilization consisting of a combination of nitrogen and phosphorus applied as a powder (12–48–8) at 3.4–5.6 kg/ha. As needed, liquid agricultural lime was applied to increase water hardness. The hardness (35.5 mg/L) and alkalinity (77 mg/L) of well water in the region are both low. This combination results in a weak buffering capacity and the proclivity for the occurrence of rare but rapid increases in pH, rising to >9.5. Thereafter, cottonseed meal was then added at 16.8 kg/ha every other day within 1 wk of stocking.

There were two treatments, juveniles stocked as either mixed-sex (control) or all-male (experimental) populations. The mixed-sex juveniles were obtained from Lauren Farms, Leland, Mississippi, and the all-male (zz) juveniles were obtained from the same commercial hatchery as those used in Study 2 in Kentucky (Aquaculture of Texas, Weatherford, TX, USA). At least three independent samples of 100 juveniles were spun in a dip net to remove interstitial water and then weighed. All-male and mixed-sex juvenile prawns were hand counted and stocked at 24,700/ha on June 4, 2012, and June 11, 2012, respectively, into four replicate ponds per treatment. The initial stocking weights of the mixed-sex (control) and all-male treatments were 0.39 ± 0.04 and 0.34 ± 0.01 g, respectively.

After stocking, prawns were fed sinking range cubes (All Natural Range Cubes, Ware Milling, Houston, MS, USA) containing 23% crude protein (D'Abramo et al. 2010), once daily for the duration of the growing season. The total amount fed was based on a 3:1 ratio of feed to anticipated total yield (1221 kg/ha) of harvested prawns. The daily rates of feed addition were based on proportions of the total amount assigned to different time intervals (days) of the growing season, 13.8% (Week 1–5), 34.5% (Week 6–10), 37.7% (Week 11–15), and 14.0% (Week 16–17). Maintenance of water quality was according to the recommendations of D'Abramo et al. (2009). Dissolved oxygen (DO) levels, measured by a YSI Model 550 or 550-A (YSI, Yellow Springs, OH, USA) were managed daily to remain at >3 mg/L based on readings in the early morning, mid-morning, afternoon, and evening (as needed, based on the time of the growing season). A fixed in-pond aerator was located at the surface of the deepest part of the pond and available to provide the equivalent of 9.88–12.35 horsepower (hp)/ha (1 hp = 746 W) as needed. Any additional aeration needed to maintain the minimum desired level of DO was provided by a tractor-driven power take-off paddlewheel. The pH of the water of each pond was routinely monitored every 3–4 d, depending on weather conditions, during the mid-afternoon.

The culture periods for the mixed-sex and all-male treatments were 112 and 120 d, respectively. As part of the termination of the experiment, water levels in each experimental pond were lowered to approximately 0.5 m at the drain end. The substrate was then removed from each pond followed by complete draining. All prawns were harvested from the bottom of the pond and counted and weighed to determine survival, mean harvest weight, and production. A random sample representing 12.4–16.3% ($x = 14.3\%$) of all prawns harvested from two ponds of each treatment was removed. Males were individually weighed and classified into one of four male morphotypes including blue claw (BC), strong orange claw (SOC), orange claw (OC), and small (SM) categories as described by Daniels (1993). Data on SOC males were later combined into the OC category. Females in the mixed-sex experimental ponds were bulk weighed and counted but were not individually weighed and classified according to the different sexual morphotypes.

Study 2 – Kentucky (High Input/High Density)

Six ponds located at the Aquaculture Research Center (ARC), Kentucky State University, Frankfort, Kentucky were prepared as described in Tidwell et al. (2000). A 0.5 hp vertical pump surface aerator (Airolator, Kansas City, MO, USA), operated nightly at the surface of the deepest area of each pond to aerate and prevent thermal stratification. Juvenile prawns were shipped by truck from a commercial hatchery (Aquaculture of Texas). The mean stocking weight was determined from a sample of 100 prawns that were blotted free of surface water and individually weighed. Individual mean stocking weight for the mixed-sex treatment was 0.34 ± 0.13 g while the all-male juveniles averaged 0.38 ± 0.19 g. On June 5, 2012, prawns were hand-counted and stocked into the 0.04 ha ponds at 60,000/ha. There were three replicate ponds per treatment. Prawns were fed a commercial sinking-extruded prawn grow-out diet containing 33% protein and 8% lipid (Rangen, Inc., Buhl, ID, USA). Feed rates were based on a standardized feeding chart (D'Abramo et al. 1995). The daily ration was divided between AM and PM feedings. Every 3 weeks ponds were sampled to obtain >30 individual prawns per pond. Prawns that composed the sample were bulk weighed and counted to determine average weight and then returned to the pond.

DO and temperature were monitored twice daily (0800 and 1600 h) using a Model 85 oxygen meter (YSI Industries). The pH of the water was also monitored twice daily (0800 and 1600 h) using a model 340i pH meter (Wissenschaftlich Technische Werkstätten, Weilheim, Germany). Total ammonia-nitrogen (TAN), and nitrite-nitrogen were monitored three times per week using a Hach Odyssey digital spectrophotometer (Hach Company, Loveland, CO, USA). Alkalinity and hardness were monitored once per week using a Hach digital titrator (Hach Company).

All ponds were supplied with artificial substrate consisting of 2.5 × 3.8 cm lightweight polyethylene bird netting (Tidwell and Coyle 2008), hung in vertical orientation, and stretched the length of the pond between metal fence posts. Surface area of the substrate was calculated based on dimensions of one side of the mesh (length × width) and was added at a rate to increase the pond bottom surface area by 100%. Prawns were cultured for 105 d. Harvest procedures were initiated in September 18, 2012. One day prior to harvest, the water levels in each pond were lowered to approximately 0.5 m at the drain end. On the following day, substrates were removed and each pond was seined three times with a 1.3 cm square mesh seine then drained. Remaining prawns were manually harvested from the bottom of the pond and all prawns were purged of mud by holding in tanks with flowing water. Total bulk weight and number of prawns from each pond were recorded. A random sample of ≥500 prawns from each pond were then individually weighed and classified into one of the following sexual morphotypes: berried females (BE), open females (OP), virgin females (VF), blue claw males (BC), orange-claw males (OC), and small males (SM) (Cohen et al. 1981; D'Abramo et al. 1989). The BE and OP morphotypes were later consolidated into a group termed reproductive female (RF) representing sexually mature females (Tidwell et al. 2000).

Data Calculation and Statistical Analyses – Both Studies

Effects of treatments on water quality and prawn growth in ponds were compared by Student's *t*-test using Statistix version 9.0 (Analytical Software, Tallahassee, FL, USA). Means were considered significantly different at $P \leq 0.05$. Measurements of growth performance were computed as follows: feed conversion ratio (FCR) = total weight of feed fed (kg)/total live weight gain (kg), and production size index (PSI) = production (kg/ha) × average weight (g)/1000. Percentage and ratio data were converted to arc sin values prior to analysis. These data are presented in the untransformed form to facilitate comparison and interpretation.

Results

Study 1 – Mississippi

One of the replicates in the all-male treatment was not included in the calculation of means due to survival being less than 50% (49.8%). The mean harvest weight (54.7 g) was comparable to the other replicates but total production was low (675.6 kg/ha). The similar harvest weights

TABLE 1. *Means (±SE) of final individual weight (g), total production (kg/ha), production stock index (PSI), percent survival, and feed conversion ratio (FCR) of either mixed-sex or all-male giant river prawns reared in ponds in Study 1, Mississippi or Study 2, Kentucky. Values within columns within studies followed by different superscripts are significantly different* ($P \leq 0.05$).

Treatment	Final weight (g)	Production (kg/ha)	PSI	Survival (%)	FCR
Study 1 – Mississippi					
Mixed-sex	34.3 ± 2.8^{b}	785 ± 74^{b}	27.5 ± 4.7^{b}	88.6 ± 4.6^{a}	3.9 ± 0.4^{a}
All-male	56.5 ± 0.4^{a}	1105 ± 37^{a}	62.4 ± 2.4^{a}	78.9 ± 2.3^{a}	2.7 ± 0.1^{b}
Study 2 – Kentucky					
Mixed-sex	30.4 ± 1.0^{b}	1581 ± 181	48.2 ± 7.1^{b}	87.7 ± 7.3^{a}	4.2 ± 0.5^{a}
All-male	42.6 ± 3.0^{a}	1866 ± 126	79.8 ± 11.0^{a}	73.8 ± 11.0^{a}	3.6 ± 0.2^{a}

combined with lower survival suggest a mortality event, presumably high pH, which occurred close to the day of harvest. As previously stated, the well water used to fill the ponds has some chemical characteristics that are fairly unique to the region and contribute to poor pH buffering capacity. This condition is the basis for the periodic occurrence of sudden and lethal increases in pH (>9.5), especially during conditions of dense phytoplankton blooms.

Mean survival for the all-male population (78.9%) was not significantly different from the mixed-sex population (88.6%). There was a significant difference between all-male and mixed-sex ponds for both harvest weight (56.5 vs. 34.3 g) and production (1105 vs. 785 kg/ha), reflecting increases of 65 and 41%, respectively (Table 1). The higher production in the all-male ponds resulted in a FCR (2.7) that was significantly lower than that for the mixed-sex ponds (3.9). The PSI for the all-male treatment (62.4) was significantly higher than that of the mixed-sex treatment (27.5).

Mean harvest weights of BC and SM were similar between treatments (Table 2). The mean weight of OC males in the all-male population increased by 22%, but this difference was not significant. The mean percentage of OC males as a percentage of the total population was 85.7% in all-male ponds and 70.4% in mixed-sex populations and corresponded to a 15% increase in SM in the mixed-sex relative to the all-male pond populations. Females were not classified into the two morphotypes in the mixed-sex treatment. The percentage of prawns reaching final weights considered marketable (≥20 g) was 94% in the all-male ponds and 81% in the mixed-sex ponds. The percentages of prawns achieving sizes considered to be premium size (≥30 g) were 91% in the all-male treatment and 74% in the mixed-sex treatment. The percentages of prawns achieving extra premium weight of ≥40 were 88% for the all-male treatment and 61% in the mixed-sex treatment.

Study 2 – Kentucky

Measured water quality variables, either monthly or overall, for both treatments were not significantly different. Overall means for water quality variables were: morning temperature, 25.2 C; afternoon temperature, 27.4 C; morning DO, 6.6 mg/L; afternoon DO, 8.7 mg/L; afternoon pH, 8.5; TAN, 0.20 mg/L; unionized ammonia-nitrogen, 0.03 mg/L; and total nitrite-nitrogen, 0.049 mg/L. Over the duration of the study, all water quality samples for the above parameters represented suitable conditions for prawn culture (Boyd and Zimmerman 2000).

Changes in average weights of sampled prawns at 3 wk intervals over the grow-out period are presented in Figure 1. At harvest, there were no significant differences between the all-male and mixed-sex treatments for survival (74 and 88%, respectively), total production (1866 and 1581 kg/ha, respectively), or FCR (3.6 and 4.2, respectively) (Table 1). However, the average individual harvest weight of prawns in the all-male treatment (43 g) was significantly greater than the average weight of prawns in the mixed-sex treatment (30 g). Also, PSI was significantly higher in the all-male treatment (80) than in the mixed-sex treatment (48).

TABLE 2. *Means (±SE) of percent distribution as percent of sex, percent of total population, and average weights (g) of each male (BC, OC, and SM) and female (RF and VF) morphotype (Kentucky only, Mississippi not determined [ND]) at harvest for either mixed-sex or all-male giant river prawns reared in ponds in Study 1, Mississippi or Study 2, Kentucky. Values within columns within studies within data type, followed by different superscripts, are significantly different ($P \le 0.05$). For Mississippi populations sampling was confined to two ponds per treatment.*

Treatment	Blue claw (BC)	Orange claw (OC)	Small male (SM)	Reproductive female (RF)	Virgin female (VF)
Variable = Morphotype as percent of sex (%)					
Study 1 – Mississippi					
Mixed-sex	9.6 ± 0.2^a	70.4 ± 3.5^a	20.1 ± 3.3^a	ND	ND
All-male	10.1 ± 1.9^a	85.7 ± 1.9^a	4.2 ± 3.3^b	–	–
Study 2 – Kentucky					
Mixed-sex	12.2 ± 2.0^a	57.8 ± 4.4^b	30.0 ± 3.6^a	32.3 ± 7.5	67.7 ± 7.5
All-male	4.7 ± 0.5^b	82.9 ± 4.2^a	12.5 ± 4.6^b	–	–
Variable = Morphotype as percent of population (%)					
Study 1 – Mississippi					
Mixed-sex	5.0 ± 0.5^a	36.0 ± 1.0^b	10.4 ± 2.5^a	ND	ND
All-male	10.1 ± 1.9^a	85.7 ± 1.4^a	4.2 ± 3.3^a	–	–
Study 2 – Kentucky					
Mixed-sex	6.4 ± 1.4^a	29.8 ± 1.1^b	15.7 ± 4.0^a	15.6 ± 4.0	32.5 ± 4.0
All-male	4.8 ± 0.8^a	82.9 ± 2.0^a	12.5 ± 4.6^a	–	–
Variable = Average Weight (g)					
Study 1 – Mississippi					
Mixed-sex	66.0 ± 1.4^a	47.6 ± 1.2^a	10.9 ± 0.7^a	36.4 ± 2.1 (composite all females)	
All-male	66.8 ± 2.2^a	58.0 ± 2.3^a	9.9 ± 2.1^a	–	–
Study 2 – Kentucky					
Mixed-sex	53.1 ± 3.6^a	39.8 ± 0.8^a	10.7 ± 0.6^a	33.4 ± 0.7	27.1 ± 0.8
All-male	56.4 ± 3.4^a	43.7 ± 2.0^a	11.6 ± 0.3^a	–	–

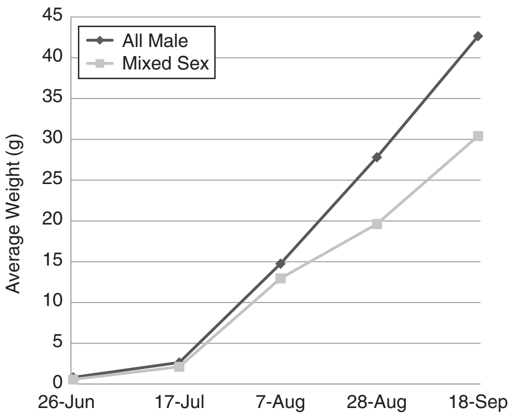

FIGURE 1. *Mean sample weights of prawns in Kentucky (Study 2) sampled triweekly from earthen ponds stocked with either mixed-sex or all-male juveniles.*

Freshwater prawns have a complex population structure and the sizes and numbers of the different sexual morphotypes can have practical implications in terms of growth, production, and even survival. Obviously there were no female morphotypes in all-male treatment ponds so comparisons are confined to changes among male morphotypes in the two treatments.

The average weight of BC, orange-claw males (OC) and small males (SM) did not differ statistically between treatments (Table 2). The number of males classified as BC and SM as a percentage of the total population also did not differ between treatments (Table 2). However, the number of prawns classified as OC males calculated as a percentage of the total population (83%) was significantly higher than that in the mixed-sex treatment (30%) (Fig. 2). When numbers of prawns classified into the different male morphotypes are presented as a percentage of sex (percentage of total males in the pond) there were large shifts in population structure. The percentage of males reaching BC status in all-male ponds (5%) was significantly lower than that in mixed-sex ponds

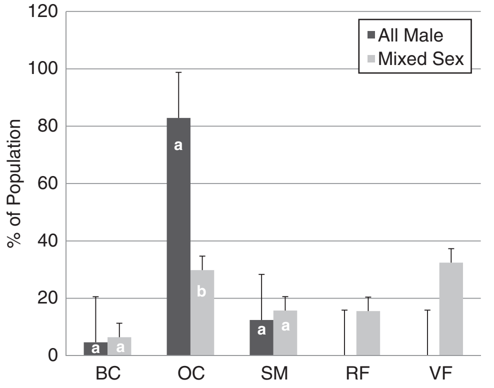

FIGURE 2. *Percent distribution in Kentucky (Study 2, % of total population) according to number of each male (blue claw [BC], orange claw [OC], and small [SM]) and female (reproductive female [RF] and virgin females [VF]) morphotypes at harvest for prawns stocked into ponds as mixed-sex or all-male juveniles. Means with different letters indicate significant treatment differences* (P ≤ *0.05) within morphotypes.*

(12%). The percentage of males classified as OC was 83% in the all-male ponds compared with 58% of total males in mixed-size ponds and this difference was significant. There was a significant decrease in the percentage of males classified as SM in the all-male treatment (12%) when compared with the mixed-sex treatment (30%).

The percentages of the population reaching final weights considered marketable (≥20 g) were 87% in the all-male ponds and 80% in the mixed-sex ponds and the difference was not significant. In terms of the percentage of the populations achieving sizes considered premium (≥30 g), 74% of the animals in the all-male treatment were ≥30 g compared with 52% in the mixed-sex treatment. This difference was also not significant. However, when treatments are compared in terms of those achieving extra premium sizes (≥40 g), 54% of the prawns in the all-male treatment reached sizes of ≥40 g while only 18% of the mixed-sex population reached ≥40 g. This difference was significant.

Marketable production expressed as total weight per unit of pond area (kg/ha) for sizes ≥20 g was 1267 kg/ha in mixed-sex ponds and 1632 kg/ha in all-male ponds (Fig. 3) and there was no significant difference. Production of premium size prawns (≥30 g) in mixed-sex

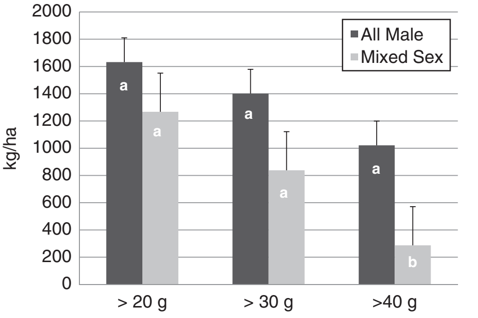

FIGURE 3. *Marketable production (kg/ha) of prawns in Kentucky (Study 2) based on minimum sizes of 20, 30, or 40 g for prawns stocked into ponds as mixed-sex or all-male. Means with different letters indicate significant treatment differences* (P ≤ *0.05) within morphotypes.*

ponds was 838 and 1401 kg/ha in all-male ponds and there was no significant difference. Production of prawns ≥40 g average weight was 1021 kg/ha in all-male prawns versus 287 kg/ha in the mixed-sex treatment and this difference was significant.

Discussion

Ponds stocked with all-male prawns produced numerically superior results in the production variables of average weight, total production, PSI, and FCR at both locations (Table 1). Improvements in average size and total production in all-male ponds are in agreement with Cohen et al. (1988). The slightly lower survival of all-male prawns at both locations is also in agreement with slightly reduced survival of all-male prawns reported by Sagi et al. (1986). The total production (kg/ha) in all-male and mixed-sex ponds in Mississippi (Study 1) were 1.6 times less than those in Kentucky, reflecting the fact that stocking rates in Kentucky were 2.5 times those in Mississippi.

Relative to the mixed-sex harvested populations, the percentages of the OC morphotype in the harvested populations from all-male ponds increased in both Kentucky and Mississippi. The smaller percentage of small males in Mississippi is most probably reflective of the lower stocking densities there. The mean increase in the percent of OC males as a percentage of total males in the all-male ponds was higher in Kentucky compared with those in Mississippi (25.1 vs. 15.3%), again likely reflective of different stocking densities. The stocking density effect was also reflected in higher mean harvest weights of the BC and OC males harvested from both all-male and mixed-sex ponds in Mississippi in comparison to those observed in Kentucky.

The OC morphotype is in many ways the most desirable morphotype. They are considered to manifest the fastest growth rate. Sagi and Ra'anan (1988) compared the relative weights of the midgut glands of the different male morphotypes, as this organ is involved in food assimilation and energy mobilization during molting, and found the OC morphotypes had significantly larger (relative to body weight) midgut glands than SM or BC morphotypes. The OC morphotype also tends to be less aggressive than the BC (Karplus and Sagi 2010) likely making them more amenable to higher stocking densities. The dressout percentage of OC is also likely greater than that of the BC as the claw weight of the OC is lower.

Certain management practices have been shown to increase the incidence of the OC morphotype including size grading of juveniles prior to pond stocking (Karplus et al. 1986) and addition of substrate (Tidwell et al. 1998), similar to what is observed with reductions in stocking densities (D'Abramo et al. 1989). High proportions of OC in all-male populations were reported even in early studies (Sagi et al. 1986). It may be that reduced competition is not the only factor allowing males to remain at the subdominant OC stage, as seen with added substrate (Tidwell et al. 1998) and lower stocking densities (D'Abramo et al. 1989). Males are known to adjust their maturation time to correspond to that of the females (Cohen et al. 1981). An absence of females could delay development of the final stage (BC) in the male maturation pathway. With development of BC males delayed, growth suppression of SM males would be absent or reduced, allowing them to advance to the OC stage (Ra'anan and Cohen 1985). With SM males not inhibited from developing to the OC stage, and with no mature females to stimulate development of BC males, a large proportion of OC males could develop.

The largest (and possibly most important) differences were seen in percentages of prawns and total production (kg/ha), achieving threshold sizes considered marketable (≥20 g), premium (≥30 g), or extra premium (≥40 g). As target sizes increased the relative performance of the all-male populations increased. In Kentucky (Study 2), the percentage of total production achieving target sizes in all-male ponds compared with mixed-sex ponds was 28% higher for ≥20 g, 67% higher for ≥30 g, and 256% higher for ≥40 g (Fig. 3). These differences for all-male ponds in Mississippi (39, 43, and 75%, Study 1) were not as large in magnitude, likely due to higher mean harvest weights that are the result of lower stocking densities. For many markets, different size prawns are differentially priced with larger prawns selling for higher prices (Tidwell and D'Abramo 2010). Under these conditions, the marketing superiority of the all-male population looks promising.

Despite some differences in management practices/protocols between the Kentucky and Mississippi locations, and the number of replicates for the statistical analysis of the weight class and male morphotype distribution in harvested populations, there are some shared conclusions about the results of stocking all-male populations. In both studies, the higher mean harvest weight and total production are evident. Common to both studies is the increase in the proportion of OC males and the higher mean harvest weights in the all-male ponds. However, the percent increase in the harvest weight of OC males in the all-male compared with mixed-sex ponds was higher in Mississippi (21.8%) than in Kentucky (9.8%).

Shifts in population structures and higher average harvest weights are important in terms of animals reaching the target weights desired in the marketplace. The stocking of an all-male population can potentially translate into higher revenues given the increased proportion of prawns achieving marketable and premium sizes. In addition, the lack of females removes the possible consumer aversion for ovigerous (egg carrying) females. However, final analysis of the economic practicality of stocking all-male rather than mixed-sex populations in temperate regions will need to be based on tradeoffs that primarily consider the increased cost of all-male juveniles relative to the increased returns derived from larger average sizes.

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